

Specification

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Acoustic Wave Transducer With Transverse Mode Suppression

5 The invention relates to a transducer or component that works with surface acoustic waves (surface acoustic wave component, SAW component) in which interfering transversal wave modes are suppressed. SAW components are used in particular as filters in portable wireless devices.

10 Known SAW components always include a piezoelectric substrate, on the surface of which is provided an acoustic spur with component structures arranged therein, e.g. interdigital transducers and reflectors. An electrical signal is converted into an acoustic wave and vice versa in the interdigital transducers.

15 The acoustic wave propagates corresponding to the mostly periodic arrangement of the electrode fingers of the transducer primarily in both longitudinal directions. Transducers are also known that are used in recursive filters and that preferably radiate the excited acoustic wave only in one longitudinal direction. During propagation of the acoustic wave, diffraction losses occur in the marginal area of the transducer due to the radiation
20 of a portion of the surface acoustic wave in the transverse direction.

In most of the piezoelectric substrates with normal dispersion, e.g. quartz, LiNbO₃ and YZ, the velocity of propagation of the excited surface acoustic waves in the acoustic spur (SAW spur) is reduced, compared to a free substrate surface, by the metallization of the
25 substrate surface. Thus, one SAW spur or several SAW spurs connected electrically to one another cooperates with the adjacent outer areas of the substrate surface in the transversal direction as a waveguide. In the waveguide, transversal wave modes, basic mode and higher modes, are excitable, the higher modes frequently contributing to unwanted resonances in the stop band or upper pass band area of the SAW component
30 and thus wastefully consume some of the energy of the wave. These resonances in

particular lead to unwanted ripples in the pass band area and furthermore are manifested in increased insertion loss of the component and interfering peaks in the frequency response of the group delay. The filter properties of the component suffer from this.

5 In previously known methods for suppressing interfering transversal modes there have been attempts to adapt the transversal excitation profile of an electroacoustic transducer so that injection of the electrical signal to the greatest extent possible results only in the transversal acoustic basic mode.

10 For instance, it is possible to vary the transversal length of the overlapping area of two adjacently arranged electrode fingers of an exciting finger pair in the acoustic spur in the longitudinal direction so that the injection of the electrical signal is improved in the transversal basic mode. This method is thus based on overlap weighting and is known, for example, from the publication by W. Tanski, Proc. 1979 IEEE Ultrasonic
15 Symposium, pages 815-823.

Alternatively, while maintaining the distance between opposing busbars of two electrodes of a transducer, it is possible to increase the length of the inactive electrode fingers, which are also called stubs and which oppose the exciting electrode fingers in the
20 transversal direction, and at the same time to correspondingly decrease the length of the overlapping area of an exciting finger pair. The excitation of higher transversal wave modes can only be avoided to a certain degree in this manner.

Another known method for suppressing higher transversal modes and/or for adapting the
25 excitation profile of a transducer to the shape of the transversal basic mode is known, for example, from DE 196 38 398 C2. An acoustic spur is divided into several partial spurs, whereby all partial spurs contribute to exciting the acoustic wave. Given N waveguide modes to be suppressed, the acoustic spur is divided into N partial spurs, whereby the excitation profile can be adapted to the form of the transversal basic mode by adjusting
30 the spur widths and/or the sign of the excitation in each of the partial spurs so that the

higher transversal modes are suppressed. A disadvantage of this method is that dividing the spur depends on the exact number of waveguide modes to be suppressed and therefore the design of the component is also complex.

5 The object of the present invention is to provide a transducer that works with surface acoustic waves and in which interfering transversal modes are suppressed.

10 The invention suggests a transducer that works with surface acoustic waves and has an acoustic spur, and arranged in the acoustic spur are component structures, in particular electrode fingers of a first and second electrode that engage one another. The acoustic spur and/or the corresponding component structures are arranged on a piezoelectric substrate. In the acoustic spur an acoustic wave is excitable that is characterized by a transversal basic mode. The transversal basic mode results from the transversal speed profile of a waveguide that is formed by the acoustic spur and the transversal exterior areas adjacent to it, whereby most of the energy of the acoustic wave is concentrated in the acoustic spur. The exterior area is a non-exciting area of the substrate that is adjacent to the acoustic spur and in which the amplitude of the acoustic wave is dampened in the transversal direction to a fraction (e.g. to 1/10) of its maximum value at the edge of the corresponding marginal area. The amplitude of the wave decreases exponentially in the exterior area in the transversal direction that faces away from the spur.

20 In addition, the excursion of the injected surface acoustic wave is called excitation strength. The acoustic spur is characterized by the excitation strength (in the longitudinal or transversal direction). The excitation strength is proportional to the difference in potential ΔU between the electrode fingers arranged in the longitudinal direction adjacent to one another and of different electrodes that together form an exciting finger pair. The excitation strength as a function of the transversal coordinate Y is called the excitation profile Ψ_y here.

In the waveguide thus formed, several transversal modes of the acoustic wave (the basic mode and its harmonics) are excitable and/or can be propagated. The maximum injection of the electrical signal is attained at a certain frequency in the basic mode of the acoustic wave when the acoustic spur in the transversal direction is designed so that the
5 corresponding transversal excitation profile Ψ_y of the wave is adapted to the shape Φ_y of the basic mode, whereby the formula

$$\int \Psi_y \Phi_y dy / \sqrt{\int \Psi_y^2 dy \cdot \int \Phi_y^2 dy} \geq \alpha$$

can be the criterion for this adaptation, where, for example, $\alpha = 0.9$ and preferably $\alpha =$
10 0.95 . Φ_y is the excursion of the transversal basic mode as a function of the transversal coordinate Y .

Given optimum injection of the electrical signal into the acoustic basic mode, the injection disappears in higher modes, since the system of transversal modes is nearly
15 orthogonal.

For this purpose the acoustic spur is inventively divided in the transversal direction into an excitation area and two marginal areas, whereby the longitudinal phase speed of the acoustic wave in the marginal area is less than in the excitation area. The wave number
20 k_y of the transversal basic mode is $(ky)^2 > 0$ in the marginal area and $(ky)^2 < 0$ in the exterior area. In the excitation area, k_y is numerically substantially smaller (e.g. by at least one order of magnitude) than in the marginal areas and the exterior areas, whereby preferably $k_y = 0$. The width of the marginal area, measured in the wavelengths, in the transversal direction is preferably essentially $\lambda_y/4$, whereby λ_y is the wavelength of the
25 transversal basic mode in the corresponding marginal area.

Because k_y is numerically substantially larger in the marginal areas than in the other areas, the excursion of the transversal mode accordingly varies in the transversal direction in the marginal areas more rapidly. Therefore, an approximately square basic
30 mode can be set in the waveguide, whose edge steepness is a function of the absolute

width of the boundary spurs and ultimately of the phase speed of the wave in the marginal areas.

5 Suppression of interfering transversal wave modes is inventively attained in that the injection of an electrical signal into the transversal acoustic basic mode is enhanced by the introduction and special design of the marginal areas of the acoustic spur. One component with suppression of interfering transversal wave modes in accordance with the invention has the advantage that during the design of such a component, the simulation of the wave propagation in only one direction (the longitudinal direction) is
10 adequate for a good match of the simulated and real transmission functions of the component. No complex simulation of two-dimensional wave propagation effects (in the longitudinal and transversal directions) is necessary.

15 The division of the acoustic spur into an excitation area and two boundary spurs differs from the known spur division into several partial spurs in that no excitation of the acoustic wave is provided in the marginal areas of an inventive component in the longitudinal direction, but rather the wave excited in the excitation area is intentionally slowed.

20 In accordance with the invention, the marginal areas are merely for adjusting the transversal waveguide basic mode (deviating from the sine) by prescribing the appropriate speed profile for the waveguide. For adjusting the shape of the transversal basic mode, it is possible for instance to vary the width of the marginal area and/or the phase speed of the wave.

25 The phase speed of the wave can be reduced, for instance in electroacoustic highly coupling piezoelectric substrates with normal dispersion (such as lithium antalate or lithium niobate), reciprocally to the metallization ratio of the surface of the substrate. It is therefore possible to slow the wave in the marginal areas using a metallization ratio
30 that is higher in reference to the excitation area. The marginal areas are each preferably

metallized to 100%, whereby the corresponding marginal area has the shape of a continuous metal strip with a transversal width of $\lambda_y/4$.

5 In piezoelectric substrates with normal dispersion and a low electroacoustic coupling factor, such as quartz, the phase speed of the wave is reduced using a higher number of electrode fingers per unit of length in the marginal areas. The propagation time of the acoustic wave in a certain direction also depends on the number of edges of the electrode fingers arranged along the wave propagation direction, because the wave is "braked" at each edge. Consequently, as an alternative to a continuous metallization of the marginal areas, the wave can be slowed, for example, by using a greater number of electrode fingers per unit of length in the marginal areas compared to the excitation area (energy storage effect). The electrode fingers in the marginal area are preferably arranged on a periodic grid. The metallization ratio in the excitation region and in the marginal areas of the acoustic spur can be selected to be the same or different.

15 In all previously known methods, the excitation profile of a transducer is adapted to the transversal basic mode. The idea in accordance with the invention of adapting the shape of the transversal basic mode to the prescribed excitation profile of the transducer has the advantage that the interfering transversal wave modes can be suppressed even in the transducers with excitation profiles that are most simple to execute.

20 In advantageous variants of the invention it is provided that it is also possible to undertake additional fine-tuning of the excitation profile of the transducer to the shape of the transversal basic mode established as described above.

25 For example, the aforementioned fine-tuning can be realized by dividing the excitation area in the transversal direction into several partial spurs, whereby each partial spur forms a partial transducer. The partial spurs and/or partial transducers are switched to one another in series and/or in parallel. The difference in potential of the exciting electrode fingers, and thus the excitation strength in the partial spurs, is reduced using serial wiring.

The partial spurs are designed identically in the longitudinal direction up to their width, whereby the width of the partial spurs is selected so that the transversal profile Ψ_y of the excitation strength in the excitation area is adapted to the shape Φ_y of the transversal basic mode.

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The invention is explained in greater detail below using exemplary embodiments and related figures. The figures use schematic depictions that are not to scale to illustrate different exemplary embodiments of the invention. Identical or identically acting parts are labeled with the same reference numbers.

10 The schematic drawings are as follows:

Figure 1 illustrates an inventive component (bottom), the change in the wave number in the transversal direction (center) and the shape of the corresponding basic mode (top);

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Figure 1a illustrates the structure of the inventive component by segment;

Figure 2 illustrates another inventive component, the excitation area of which is divided into partial spurs that are wired serially to one another (bottom), the corresponding transversal excitation profile and the shape of the transversal basic mode (top);

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Figure 3 illustrates another inventive component, the excitation area of which is divided into partial spurs that are wired to one another serially and in parallel (bottom), the corresponding transversal excitation profile and the shape of the transversal basic mode (top);

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Figure 4 illustrates another inventive component with several acoustic spurs that are wired one after the other (bottom), the corresponding transversal basic mode and the change in the wave number in the transversal direction (top);

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Figure 5 illustrates the transmission function of a filter with a conventionally designed acoustic spur (simulation with and without taking into account the transversal excitation profile) (a) and the corresponding group delay (b);

Figure 6 illustrates a) the transmission function of a filter with an inventively designed acoustic spur (simulation with and without taking into account the transversal excitation profile) in a transversal excitation profile adapted to the basic mode; and b) the corresponding group delay;

Figure 7 illustrates a) the excursion of the transversal wave modes that can be propagated in the acoustic spur in a non-adapted transversal excitation profile; and b) the excitation strength corresponding to the modes;

Figure 8 illustrates (a) the excursion of the transversal wave modes that can be propagated in the acoustic spur in a transversal excitation profile that has been adapted to the basic mode; and (b) the excitation strength corresponding to the modes.

Figure 1 illustrates an inventive component with an acoustic spur AS that is arranged on a piezoelectric substrate such as quartz in which a surface acoustic wave can be propagated in the longitudinal direction X (bottom), the square of the wave number k_y of the transversal mode as a function of the transversal coordinate Y (center) and the transversal basic mode Φ_y resulting from the k_y profile (top).

The acoustic spur AS is divided into an excitation area MB and two marginal areas RB1 and RB2. The width of the marginal area in the transversal direction is approximately $\lambda_y/4$, whereby λ_y is the wavelength of the transversal basic mode in the marginal area.

The component has two electrodes E1 and E2, each of which includes a busbar and electrode fingers attached to it. The electrode fingers of different electrodes are alternately arranged in the excitation area and form exciting finger pairs. The electrode fingers in one marginal area all belong to the same electrode and are therefore inactive, i.e. the acoustic wave is not excited in this marginal area. The marginal areas in this exemplary embodiment have a lattice structure, whereby the periodicity of the lattice is smaller compared to the mean grid of the excitation area MB, whereby the excess edges of the electrode finger lattice in the margin area and opposite the excitation area contribute to reducing the phase speed of the acoustic wave induced in the marginal area.

The excitation profile of the acoustic spur AS is defined by the excitation area and is rectangular in this variant of the invention.

The acoustic spur AS and the exterior areas AU1, AU2 adjacent to the acoustic spur in the transversal direction together form a waveguide. The transversal waveguide modes are characterized by a phase factor e^{iky} . For bound wave modes, the transversal wave number k_y is real within the core area of the waveguide (i.e. excitation area MB) and imaginary in the jacket area of the waveguide (exterior areas AU1, AU2).

In the excitation area MB, k_y is substantially smaller than k_y in other areas. When $k_y = 0$ (in the excitation area), the basic mode has a plateau in this area, i.e. the excursion of the wave in the excitation area is constant in the transversal direction Y.

In the exterior areas AU1, AU2 that are outside of the acoustic spur AS and are adjacent to it in the transversal direction, k_y is imaginary or $(k_y)^2 < 0$. Therefore the amplitude of the wave in the exterior areas AU1, AU2 drops exponentially in the transversal direction.

The transversal wave number k_y is real or $(k_y)^2 > 0$ in the marginal areas RB1, RB2. A transition occurs from the maximum amplitude in the excitation area to a fraction of the amplitude at the edge of the exterior area.

Using the width of the marginal area selected as described above, the shape of the transversal basic mode is established so that the amplitude of the wave drops outward exponentially to the exterior areas and at which in the marginal areas in the transversal direction a standing wave forms, whereby the convexity of the standing wave is at the edge of the excitation area and of the marginal area or of the nodes of the standing wave at the edge of the exterior area. This is how the shape of the basic mode is maximally adapted to the shape of the rectangular excitation profile of the acoustic spur AS.

The value of the wavelength λ_y in the marginal area is a function of the velocity of propagation of the wave in the longitudinal direction, which in turn depends on the grid of the electrode finger lattice in the marginal area. The absolute width of the marginal area can be selected to be different (depending on the prescribed value λ_y). The width of the marginal area measured in wavelengths is always $\lambda_y/4$. The steepness of the corresponding edge of the basic mode can be adjusted using the change in the absolute width of the marginal area.

The greater the wave number k_y in the marginal area, the smaller the corresponding wavelength and consequently the absolute width of the marginal area. At large k_y values, the steepness of the edges of the transversal basic mode increases accordingly.

Figure 1a is an illustration by segment of an inventive component that is designed as a recursive transducer.

However, it is also possible to at least partially design the excitation area of the component in the longitudinal direction as in a normal finger transducer, known as such, with interdigital fingers arranged on the periodic grid, or as in a split finger transducer, known as such.

In another variant of the invention, in particular with piezoelectric substrates with a high electroacoustic coupling (such as lithium niobate or lithium antalate), in which the short-circuit on the fully metallized surface leads to a significant reduction in the phase speed, the marginal areas can alternatively be designed as continuously metallized areas with a transversal width of $\lambda_y/4$.

In practice, it has not been possible to attain a perfectly rectangular transversal basic mode by introducing the marginal areas because the absolute width of the marginal areas cannot be selected to be as small as desired. Therefore, in further variants of the invention the transversal excitation profile of the transducer is fine-tuned to the transversal basic mode, e.g. by dividing the excitation area into several partial spurs. Such fine-tuning is only possible in a very narrow frequency range because the shape of the basic mode depends on frequency.

Figure 2 illustrates a further development of the invention in which the excitation area MB of the acoustic spur AS is divided in the transversal direction into four partial spurs TB1, TB2, TB3 and T4. The partial spurs are switched electrically in series.

Illustrated at the bottom of Figures 2 and 3 is a part of the acoustic spur AS, and the corresponding excitation profile Ψ_y of the excitation area as well as the shape of the transversal basic mode Φ_y are illustrated schematically at the top.

All partial spurs of this type of divided excitation area are identically designed in the longitudinal direction, whereby the widths of the partial spurs are preferably selected to be different. The partial spur with the number i has a width b_i .

The difference in voltage between the electrodes E1 and E2 is U . The excitation strength of an electrode finger pair in a partial spur is proportional to the difference in voltage U_i between the electrode fingers. Conversely, U_i depends proportionally on the capacity of

the partial spur, which in turn is directly proportional to the width b_i of the partial spur.

The following applies:

$$U_i = \frac{b_i^{-1}}{\sum_k b_k^{-1}} U.$$

- 5 It is therefore possible to intentionally adjust or weight the excitation strength in one partial spur i by changing its width. Given serial wiring of the partial spurs, the impedance of the acoustic spur AS with a divided excitation area is correspondingly larger than the impedance of an acoustic spur with a non-divided excitation area.
- 10 In order to maintain the impedance of the acoustic spur divided into partial spurs, it is possible to wire a few of the partial spurs to one another serially and to wire this serial circuit to another partial spur or to several partial spurs in parallel (see, for example, the exemplary embodiment illustrated in Figure 3).
- 15 The excitation area MB is divided into the following partial spurs: a center partial spur MT and two marginal partial spurs RT1, RT2. The marginal partial spurs RT1, RT2 are switched in series with one another, whereby the serial circuit of the partial spurs RT1 and RT2 is switched parallel to the center partial spur MT. The width of the center partial spur MT is substantially greater than the width of the marginal partial spur RT1, RT2 –
- 20 preferably by at least a factor of 5. The impedance of the acoustic spur AS is largely determined by the impedance of the partial spur MT, which is wider. The reduction in the excitation strength in the marginal partial spurs RT1 and RT2 compared to the center partial spur MT, to which the voltage U is applied, is attained by dividing the applied voltage U between the serially wired marginal partial spurs RT1 and RT2.
- 25 Figure 4 illustrates another variant of the invention. Figure 4 illustrates by segment an inventive component (bottom), the corresponding transversal basic mode and the square of the transversal wave number as a function of the transversal coordinate (top).

In this variant, an additional acoustic spur AS' is provided that is divided – similar to the acoustic spur AS – into an excitation area MB' and marginal areas RB1' and RB2'; it is essentially identical to the acoustic spur AS. In this exemplary embodiment, the acoustic spurs AS and AS' are electrically switched in series with one another, whereby they are arranged in the transversal direction parallel to one another. An intermediate area ZB is located between the acoustic spurs AS and AS'. The widths of the marginal areas RB1, RB2 and RB1', RB2' of the acoustic spurs AS and AS' are selected so that k_y in the intermediate area ZB is substantially smaller (e.g. by at least one order of magnitude) than in the marginal areas RB1, RB2 and in the exterior areas AU1, AU2. The phase speed in the excitation areas MB, MB' of different acoustic spurs AS, AS' and in the intermediate area ZB is essentially the same, because otherwise the plateaus of the transversal basic mode could not be attained in both excitation areas.

Furthermore, it is possible to wire the acoustic spurs that are arranged parallel in parallel with one another. It is also possible to combine one serial and one parallel wiring of the spurs when there are more than two acoustic spurs arranged in parallel.

In each additional acoustic spur of a component designed with several spurs, the marginal areas are designed to be $(k_y)^2 > 0$, where although the acoustic wave is not excited, the wave excited in the corresponding excitation area can be propagated in the longitudinal direction. One intermediate area with a small k_y is provided between each two acoustic spurs. There is no excitation of the acoustic wave in the intermediate areas. Each intermediate area is preferably designed as a lattice, whereby the number of electrode fingers per unit of length is preferably the same in all excitation areas and in all intermediate areas, and the metallization ratio of the surface area is preferably the same in these areas. The electrode fingers in the intermediate area ZB are preferably arranged on a periodic grid. Thus the electrode fingers can also be periodically arranged in the excitation areas or can form unidirectionally radiating cells.

The shape of the transversal basic mode with an approximately constant excursion in the areas that correspond to the excitation areas, and the disappearing excursion in the intermediate areas, can be adjusted by appropriately selecting the absolute widths of the marginal areas, whereby the width of a marginal area, measured in wavelengths, is
5 always a quarter wavelength. In this manner the shape of the transversal basic mode is adapted to the excitation profile of a multi-spur arrangement.

Figure 5 illustrates a) the simulated transmission function of a filter with an acoustic spur with a rectangular transversal excitation profile that does not have any marginal areas
10 (i.e. the transversal excitation profile is not adapted to the shape of the transversal basic mode), and b) the corresponding frequency of the group delay.

The curves 1 and 1' correspond to a 1D simulation of the transmission function (1) or the group delay (1'), i.e. to a simulation without taking into account the wave propagation in
15 the transversal direction. The curves 2 and 2' correspond to a 2D simulation of the transmission function (2) or the group delay (2''), i.e. to a simulation taking into account the wave propagation in the transversal direction. The 2D simulation corresponds to a real behavior of the filter.

Both the real transmission function 2 and the real group delay 2' in the pass band area have a deviation of 1D behavior (curves 1 and 1') that manifests itself as an unwanted waviness of the pass band area. Additional secondary maximums in the amplitude are located on the right edge of the transmission function 2.

The cause of the secondary maximums are higher transversal wave modes, the phase factors of which are schematically illustrated as a function of the transversal coordinate –
25 curves 11, 12 and 13 – in Figure 7 at the top and their relative intensities in Figure 7 at the bottom.

The transversal mode with the ordinal number 1 is the transversal basic mode that is sinusoidal given a conventionally designed acoustic spur (with an excitation area without marginal areas) (see curve 11 in Figure 7). The relative intensity of the first transversal mode is approx. 90%. Furthermore, additional transversal wave modes with odd ordinal numbers are excited in an acoustic spur designed in this manner. A standing acoustic wave that corresponds to the second transversal wave mode (curve 12) cannot be excited due to symmetry conditions.

In this instance, the relative intensity of the third transversal wave mode (of the second harmonic of the basic mode, see curve 13 in Figure 7) is approx. 9%, and the relative intensity of the fifth wave mode, not shown in Figure 7, is approx. 1%.

The injection of the electrical signal into the third and fifth transversal modes occurs because the transversal excitation profile of the acoustic spur is rectangular, whereas the shape of the transversal mode is sinusoidal. These modes lead to unwanted resonances above the pass band area of the filter that cause the filter quality (and also the insertion loss in the pass band area) to worsen.

The higher transversal wave modes are not excited in the excitation profile and the shape of the transversal basic mode that are inventively adapted to one another.

Figure 6 illustrates the simulation of the transmission function of a filter with an inventively designed acoustic spur in accordance with Figure 1a (a) with and without taking into account the transversal excitation profile and the corresponding group delay as a function of frequency (b). The curves 3 and 3' relate to a 2D simulation of the inventive filter.

The shape of the basic mode in an acoustic spur of this type is approximately rectangular and is therefore adapted to the excitation profile.

The phase factors of the transversal waveguide modes, which are excitable and/or can be propagated in the acoustic spur designed in accordance with Figure 1a, are illustrated at the top of Figure 8, and the relative intensities of the modes are illustrated at the bottom of Figure 8. The phase factor of the first, second and third transversal modes corresponds to the curves 11', 12' and 13'. The relative intensity of the higher transversal modes is very slight compared to the intensity of the transversal basic mode.

The curves 14 and 14' and Figures 7 and 8 depict the speed profile of one of the waveguides corresponding to the acoustic spur, whereby the velocity of propagation of the wave is intended in the longitudinal direction. Figure 8 illustrates that the velocity of propagation of the wave in the marginal areas of the inventive acoustic spur is smaller than in other areas of the waveguide.

In principle, the invention can be used in all SAW components known as such, e.g. double mode SAW filters, normal finger transducers and recursive filters, and is not limited to the number of elements illustrated in the figures or to specific frequency ranges.